Chapter 6
Water Quality Incidents

Chapters 3 through 5 of this report describe general theoretical and technical background information relating to the potential for hydraulic fracturing to impact USDWs. The reported incidents in this section reflect the opinions of the citizens living near coalbed methane operations who have expressed concerns about contaminated drinking water wells (or, in some cases, drinking water wells with water quantity impacts such as reduced production). EPA has contacted and been contacted through letters or telephone calls from citizens reporting they believed their water wells were impacted by coalbed methane production in the San Juan Basin, the Black Warrior Basin, and the Powder River Basin. Stakeholders commenting on the study methodology (*Federal Register*: July 25, 2000; Volume 65, Number 143; Page 45774-45775) requested that, in addition to relying on data from formal studies, EPA also consider personal experiences with regard to coalbed methane impacts on drinking water wells.

Most of the reported incidents could not be confirmed through review of other data sources or peer-reviewed publications. For Phase I, EPA consulted with state agencies to determine if they had received the reports of ground water problems, learn of any follow-up steps typically taken by the state, and report their overall findings regarding any impacts hydraulic fracturing of coalbed methane wells has had on ground water.

There are activities or conditions other than hydraulic fracturing at coalbed methane production sites, such as surface discharge of fracturing and production fluids, poorly sealed or poorly installed production wells, and improperly abandoned production wells, that potentially account for nearby contaminated wells.

This chapter summarizes correspondence EPA has had with individual citizens and states, organized by basin:

- San Juan Basin (Colorado and New Mexico)
- Powder River Basin (Wyoming and Montana)
- Black Warrior Basin (Alabama)
- Central Appalachian Basin (Virginia and West Virginia)

The purpose of this chapter is to: 1) document reported incidents from citizens about impacts to ground water that they believe were associated with coalbed methane production wells; 2) identify the follow-up actions taken by the states in response to these reports, and; 3) discuss the states' findings regarding impacts hydraulic fracturing of coalbed methane wells has had on ground water. Table 6.1, presented at the end of the chapter, lists representative incidents that associate water quality/quantity with coalbed methane activity for each of the four basins.

6.1 San Juan Basin (Colorado and New Mexico)

In the San Juan Basin region, citizens have reported coalbed methane development has resulted in increased concentrations of methane and hydrogen sulfide in their water wells for over a decade. Other complaints surrounding CBM development include the loss of water, the appearance of anaerobic bacteria in water wells, and the transient appearance of particulates. In conversations with EPA, most citizens and local government officials did not specify hydraulic fracturing as the specific cause of well water problems. Summaries of reported incidents and state follow-up are discussed in Sections 6.1.1 and 6.1.2 below.

6.1.1 Summary of Reported Incidents

- EPA spoke with a former county employee, who worked for Exxon performing hydraulic fracturing jobs in an earlier career (Holland, 1999). As a county employee, he took measurements for methane and hydrogen sulfide inside homes in response to citizen complaints. According to his information, there were not significant problems until the shallowest formation, the Fruitland coal, began being developed. He believes that the main route of contamination is from older, poorly cemented wells. The county official estimated that hundreds of wells have been impacted. He said the biggest problem associated with the apparent effects of CBM development is explosive levels of methane and toxic levels of hydrogen sulfide in homes. In his opinion, this is due to removal of water rather than hydraulic fracturing.

- The San Juan Citizens Alliance estimated that hundreds of water wells have been affected by CBM production in the Durango, CO area.

- A lawyer who represented several Durango citizens whose wells were contaminated allegedly due to CBM development stated that there have always been methane seeps in the river, which have manifested as bubbling water (McCord, 1999). But in the early 1980s, companies began producing methane from the Fruitland and shortly thereafter, people began to see increased concentrations of natural gas in their water wells.

- One individual reported he had two wells that were degraded from increased methane levels. According to this individual, his neighbor’s pump house door was blown off, presumably as a result of explosive levels of methane. Amoco bought three ranches after County officials tested indoor air and found extremely high levels of methane. This individual also told EPA staff that an area on the Southern Ute tribal land has increased levels of hydrogen sulfide at the surface. He reported he had also heard of black water due to pulverized coal.

- Another private well owner claimed that her neighbors’ wells are contaminated by gas infiltration from dewatering. First methane contaminates the well, and then hydrogen sulfide, followed by anaerobic bacteria. She claimed that data exists showing that methane concentrations in water have increased by 1,000 ppm.

- EPA Region 8 received letters from citizens who were concerned that CBM development had contaminated their water with methane and hydrogen sulfide. The EPA employee receiving the complaints looked into the situation but thought it was not within EPA's jurisdiction because the contaminants are naturally occurring.

- During a visit to Durango, Colorado, EPA visited with several citizens who experienced problems with their water wells they claim were due to coalbed methane development. Most of the citizens experienced water loss, however, two well owners from New Mexico claim that their water was affected by hydraulic fracturing. According to their accounts, their water turned cloudy with grayish sediment a day or two after nearby fracturing events. Eventually the well water returned to its normal appearance.

- EPA also toured the area during that same visit. EPA staff viewed areas where patches of grass and trees were turning brown and dying. In some places, large, old-growth trees were located within the patch indicating that the area previously had prolonged normal soil conditions. Many citizens and some local officials believed that the areas suffered from increased methane and decreased air in soil gas within the shallow root zone.

- According to one La Plata County official, people have called the county when wells are hydraulically fractured reporting that well water flow decreases (Keller, 1999). He reported that "a lot" of people are hauling water due to water loss. The county official stated that in two separate reports, well owners noticed problems with their well water approximately two weeks after nearby fracturing events. They reportedly believe hydraulic fracturing is responsible because the timing of water loss coincides with fracturing. Citizens know when gas producers fracture wells because they can see and hear the operation, which involves several trucks, tanks, manifolds, and mobile trailers. The county official pointed out that the formation being developed, the Fruitland, is located approximately 2,400 feet below ground surface and water wells are generally drilled from 100 feet to 200 feet below ground surface. He qualified his statements by pointing out that wells do go dry for a variety of reasons.

- EPA contacted the Colorado Department of Health, which has primacy for the Safe Drinking Water Act. An official EPA spoke with stated they believe that water removal associated with CBM development has caused problems in private water wells (Bodnar, 1999).

- EPA received one complaint from a citizen living in the Raton Basin in Trinidad, Colorado. She reported that water wells in her area have begun to decline in production and quality, oftentimes producing more and more gas. She believes the decline of water wells in her area is due to dewatering associated with coalbed methane production.

6.1.2 State Agency Follow-Up (Colorado Oil and Gas Conservation Commission)

The Colorado Oil and Gas Conservation Commission (COGCC) is responsible for environmental issues related to oil and gas production in the state of Colorado. The COGCC respond to every complaint called in to their office (Baldwin, 2000).

COGCC staff believes the 20,000 unregulated septic tanks installed as a result of increased population and development may be the cause of coliform bacteria detected in many wells. The septic tanks may supply some of the nutrients used by the methanogenic bacteria to produce the biogenic methane. Based on their observations during drilling monitoring wells in the San Juan Basin, there are very thin coal zones and carbonaceous shales in the Animas and Kirkland Formations, which overlay the Fruitland. This organic material could be the main source of “food” for the methanogenic bacteria. The increase in rural residential development, that has resulted in more people drilling more water wells leads to more water wells being drilled into aquifers that already have methane in them. So, more people come in contact with both the biogenic, and in some places, the thermogenic methane.

The COGCC staff believe that increased methane concentrations found in water wells and buildings in some areas are also partially due to old, improperly abandoned gas wells and older, deeper conventional gas wells in which the Fruitland Formation was not completely isolated. The state bases their opinions on monitoring and studies conducted in the San Juan Basin in response to complaints. According to COGCC officials, the mitigation program focused on sealing old, improperly abandoned gas wells appears to have reduced methane concentrations in approximately 27 percent of the water wells sampled. They believe over time methane concentrations will decrease in other water wells where the source of the methane was gas wells. There are other areas of the San Juan Basin where the methane in the water wells is produced by methanogenic bacteria in the aquifer. Methane concentrations in water wells in these areas probably will not decrease.

Officials cite studies that use stable carbon and hydrogen isotopes of methane and gas composition to differentiate between thermogenic methane from the Fruitland, Mesaverde, and Dakota Formations, and biogenic methane that is produced in shallower formations by naturally occurring methanogenic bacteria. By 1998, approximately 2/3 of the water wells for which gas isotopic analyses had been performed appeared to contain biogenic gas, while 1/3 appeared to contain thermogenic gas.

The state also pointed out that in the interior basin, 1,100 feet of shale separates the Fruitland and the shallow formations in which private wells are completed. This fact probably precludes hydraulic fracturing from affecting private wells.

EPA spoke with a District Geologist employed at the New Mexico Oil Conservation Division (NMOCD). He reported that their office received many complaints several years ago that methane had contaminated water wells (Chavez, 2001). The state held water fairs at which they accepted and analyzed water samples from anyone who wanted to have their water tested. They initiated a program that cemented wells (some active, some abandoned) and have a cementing policy that no open holes are allowed 100 feet above casing string. He said that program seemed to solve the problem and they have not received many complaints lately.

Review of Major Studies

EPA reviewed reports summarizing major studies in order to determine if they contain any information pertaining to hydraulic fracturing of coalbed methane (CBM) strata in the San Juan Basin and its impact, if any, to the quality of water in drinking-water aquifers in that Basin. EPA reviewed these reports with respect to the two mechanisms that could potentially threaten USDWs: direct injection of hydraulic fracturing (HF) fluids into a USDW, and movement of HF fluid and/or methane through hydraulic fractures into a USDW. The reports did not address hydraulic fracturing directly and very little information was useful in addressing the question specific to this study: *Does hydraulic fracturing of coalbed methane wells threaten USDWs?*

<u>Methodology:</u>

In order to respond to the question, EPA performed a literature review by searching the Water Resources Abstracts and GeoRef databases for technical articles, books, proceedings, etc., on the following key words, separately, or in combination: coalbed (and coal gas) and ground and water (and groundwater) and methane and contamination and hydraulic fracturing (and hydrofracing) and (San and Juan and Basin). From the results of these searches, EPA was able to obtain all but a few of the documents that EPA had selected. Major studies EPA reviewed were:

> USGS 1994 Report – conducted monitoring and gathered data describing methane concentrations in ground water in the San Juan Basin area.
>
> BLM North San Juan Basin White Paper – provides a thorough history of coalbed methane development and documents observations of early environmental impacts from development in the San Juan Basin.
>
> San Juan Basin Summary of Bradenhead Testing and Ground Water Quality – prepared by the COGCC to summarize the status of ground water quality issues in the Durango area, monitoring, and remediation conducted to address the problems, and COGCC staff conclusions.
>
> Beckstrom and Boyer - a paper describing findings of four ground water sampling programs, three conducted by the New Mexico Oil Conservation Division and one by Amoco Production Company.

> San Basin 3M Project – an interagency project devoted to monitoring, modeling, and measuring. Project is designed to last over many years to describe long-term impacts to ground water from coalbed methane development activities.

EPA reviewed these reports to determine if any information could be garnered to address the issue of hydraulic fracturing impacting ground water. The findings of those reviews are described below.

<u>Background:</u>
The U.S. Dept. of Interior's Bureau of Land Management (BLM) (1999) provides a history of gas seeps and early methane contamination of drinking-water wells. Definitive identification of the source strata for the methane seeps and for the methane in water wells has not been documented:

> "Historically documented naturally occurring gas seeps throughout the San Juan Basin existed prior to oil and gas drilling operations. ...
> Shallow water wells penetrating Fruitland and Menefee coalbeds around the Basin rim have historically produced methane gas. Especially notable in La Plata County, Colorado, are seeps at the northern and western rim of the San Juan Basin. Known gas seeps include the Carbon Junction area where the Animas River crosses the Fruitland Formation."... " In approximately 1968, several water wells were drilled in the Cedar Hill, New Mexico area, but the water was unusable due to the strong sulfur odor (Kearl, 1988). As early as 1980-1985, new seeps not associated with Basin rim outcrops, but interior to the Basin, appeared to be forming in pastures in the Animas River Valley south of Durango near Bondad, Colorado and Cedar Hill, New Mexico (Shuey, 1990; Beckstrom and Boyer, 1991). Rural property owners in the Cedar Hill and Bondad areas noticed bubbles in the Animas River and in their tap water. Water well pumps cavitated as natural gas exsolved from the groundwater so rapidly that some pumps failed to perform. Several pump houses exploded when methane gas accumulated in the confined spaces and were ignited by a spark, possibly generated by a pressure switch or electric motor brushes. ... Gas seeps in soils that overlie Mesaverde sandstone outcrops were noted in the mid-1990's as manifesting patches of dead grass in pastures northeast of Durango along CR #240. (History of Natural Gas Seeps in the Northern San Juan Basin)

> "Shortly after the onset of CBM production in La Plata County in the late 1980's, a local citizens group voiced concern about an alleged increase in natural gas contamination of domestic water wells. U.S. Representative Ben Nighthorse Campbell initiated the formation of a committee to address the concerns. As an outgrowth of the Campbell Committee, the U.S. Geological Survey began a study in July 1990. This study focused on documenting the occurrence of natural gas in near-surface ground water and in soils adjacent to gas wells in the Animas River Valley in the San Juan Basin between Durango, Colorado, and Aztec, New Mexico. From analysis of water chemistry in samples collected from near-surface

> aquifers at domestic water wells, the study sought to identify and map the occurrence, determine potential sources, and suggest possible pathways through which natural gas might migrate to near-surface aquifers. Included was the investigation of the relationship between methane concentrations and mapped geologic fractures.

This study (Chafin, 1994) showed measurable concentrations of methane (greater than the detection level of 0.005 mg/L) in 34 percent of the samples tested, with bedrock wells exhibiting higher concentrations than alluvial wells." (Early 1990 La Plata County Studies of Groundwater-Entrained Methane)

> "In 1993, the emphasis for monitoring and assessment shifted toward the Basin fringes. While Basin-interior shallow groundwater contamination with thermogenic methane was being addressed by re-establishing gas well integrity, other concerns arose concerning Basin periphery water wells and Fruitland coalbed outcrops/subcrops at the San Juan Basin rim. In August 1993, a resident of Pine River Ranches Subdivision notified the COGCC of gas contamination in his shallow (34 foot-deep) water well and announced his recent observation that streams of gas bubbles were rising through the water of the nearby Los Pinos (Pine) River. As the BLM was engaged elsewhere in groundwater testing for entrained methane determinations in domestic wells proximate to BLM jurisdictional lands, SJRA services were elicited in response to this newly recognized situation. Significant concentrations of entrained methane were detected in samples of water from the well in question and from several other nearby domestic wells. This is in a topographically low area where the Los Pinos River has scoured a valley through the hogback at the northern rim of the San Juan Basin. Nine to thirty-five feet of alluvium overlie the Fruitland Formation subcrop in this valley. Four residences were situated over the Fruitland subcrop in the Pine River Ranches Subdivision. Explosive levels of methane were detected in the crawl spaces of two. Since 1987 eleven Fruitland coal wells had been drilled within two miles of the Pine River Ranches Subdivision." (Gas Seepage at the Northern Basin Fringe)

Chafin (1994, pg. 16) reported: "Most measured methane concentrations in ground water in the study area during August-November 1990 were less than the reporting limit of .005 mg/L. ... At 70 of 205 sites (34 percent), concentrations equaled or exceeded the reporting limit.

Beckstrom and Boyer (1991, pages 372-3) state:

> "In 1985, a landowner in the study area reported to the New Mexico Oil Conservation Division (NMOCD) that gas was bubbling out of his alfalfa field and in the Animas river adjacent to that field ... . This and other reports of natural gas in water and deterioration of water quality prompted domestic water well sampling by that agency."

> "In 1989 the public concern became so great that the New Mexico Environmental Improvement Division and the NMOCD sponsored a "water fair" in April, 1989 ..."

> "Four domestic water well sampling programs were implemented…"

<u>Presence of Fruitland Formation Methane in Shallow Drinking-water Wells:</u>

Although subject to some debate, the weight of evidence indicates that FF methane is present in shallow DW wells.

Chafin (1994), addressed gas migration through natural fractures (see below); he concluded that these fractures are not significant pathways. The confounding effects of natural features, such as fractures and seeps, and of preexisting, manmade features, such as well annuli and cathodic protection wells/groundbeds, make a definitive answer unlikely. That is, although FF methane appears to be present in the shallow DW aquifer, transfer of methane from the FF can easily be explained by the presence of such conduits as well annuli and cathodic protection wells/groundbeds.

Hydraulic fractures can, and sometimes do, extend "out of zone"; indeed, fracture excursions out of zone are an area of interest in the energy industry. For these units, unlike for conventional methane traps, excursions out of zone are not immediately obvious in the absence of sophisticated sensing equipment. Identifying the movement of HF fluids through hydrofractures is difficult, because of the absence of "observation ports." However, Diamond (1987) used coal mines as ports to view the movement of flourescent paint in hydraulic fractures. In his study, government-sponsored stimulation treatments were "mined-through to determine the effects on the coalbed and roof strata." All but one of the stimulations occurred in coalbeds in the eastern U. S.; one stimulation was performed in Utah. In the Diamond study, "Penetration of strata overlying coalbeds was observed in nearly half of the treatments intercepted. Most of these occurrences have been interpreted to be penetrations into joints or other preexisting planes of structural weakness." (page 243) Whether or not the target units in this study were CBM units, this observation highlights a complicating factor, the possibility that a vertical fracture, too short to extend to a USDW, intersects a preexisting conduit that <u>does</u> extend into a USDW.

The BLM (1999) stated:

> "...Inadequately cemented conventional gas well bores and extraction of produced water from coalbed methane (CBM) wells are suspected of contributing to natural gas resource losses and to methane migration into surface soils and groundwater. As methane production progressed, some residents noticed an apparent increase in the occurrence of methane in their domestic water wells, while others also noticed the presence of gas seeps in pastures, manifested by dead vegetation. During the next few years, other events were noticed that time-correlated with recent coalbed methane (CBM) production." (Part I, Introduction)

The same report also stated:

> "Shortly after the onset of CBM production in La Plata County in the late 1980's, a local citizens group voiced concern about an alleged increase in natural gas contamination of domestic water wells.... the U.S. Geological Survey began a study in July 1990. ...
>
> Shuey (1990) reviewed gas composition data of samples drawn from domestic water wells and seeps between Bondad, Colorado, and a few miles south of Aztec, New Mexico. He concluded that approximately half of the samples contained gas similar in character to that produced from Fruitland Formation coalbeds." (section on Early 1990 La Plata County Studies of Groundwater-Entrained Methane)

Cox et al (1995) analyzed gas from a domestic well withdrawing from the alluvium directly overlying the FF, and gas from a nearby FF gas well:

> "A gas sample from the resident's water well and gas from a nearby Fruitland Coal gas well were analyzed, and the gas composition and carbon-13 isotope ratios in both samples were essentially the same, suggesting the gases have a common source. A water sample from the resident's well indicated the water contained 680 ppm total dissolved solids, predominantly sodium bicarbonate. These values are typical of Fruitland produced water in this area, but are substantially different from the other domestic water wells in the area (100-200 ppm). Thus, both the gas and water analyses indicated the resident's water well was in communication with the Fruitland formation." (pg. 487)

Chafin (1994, pg. 4) states:

> "Gas-composition data from a variety of sources in the Animas River valley between Bondad, Colorado, and a few miles south of Aztec, New Mexico, were reviewed by Shuey (1990 [in Chafin, 1994]). He concluded that about half of the samples from domestic water wells and seeps in fields and the river contained gas from the Fruitland Formation ...."

While there is some belief that the methane in shallow domestic wells is derived from unregulated septic systems (Zahradnik and Wickman, 1999), there is some controversy.

Chafin (1994, pg. 41) states:

> "The likelihood that sewage-derived methane accounts for a substantial fraction of methane detections in alluvial wells is discounted by 1) the spatial association of most methane-affected alluvial wells with methane-affected bedrock wells or near documented gas wells having gas leaks or uncemented annuli, and 2) clustering of most alluvial water wells not affected with methane in areas where

> housing densities are large (at and south of Cedar Hill, New Mexico) and where potential contamination with sewage products would be most likely to occur.
>
> "The discussion in the preceding section indicates that most gas in water, soil, external gas-well casings, and cathodic-protection wells probably is thermogenic gas from deep reservoirs. Thermogenic gas in the near-surface environment of the study area primarily originates from 1) conventional gas reservoirs, including the Dakota sandstone, Mesaverde Group, Lewis Shale, and Pictured Cliffs Sandstone, and 2) coals in the Fruitland Formation. Less important sources include sandstones in the Fruitland Formation and the Kirtland Shale."

However, not all authors are in agreement about the source of methane in shallow DW wells.

Beckstrom and Boyer (1991) state:

> "Methane was detected in solution in many of the gas wells in the study area, but the source of the compounds has not been determined."

Beckstrom and Boyer (1993, pg. 71) state:

> "the Fruitland coal gas can migrate vertically behind uncemented wellbores that offset Fruitland coal gas wells, ... and that methane detected in domestic water wells near Fruitland coal development cannot be correlated directly to Fruitland coal gas development."

Nature of Conduits:

While there is evidence cited in the BLM report for the presence of FF methane in some shallow DW wells, identification of the specific conduits through which the methane has been transported is difficult, and in real-world settings, virtually impossible to determine with certainty.

The EPA's specific concern, whether or not these conduits include fractures created by hydraulic fracturing, is rarely discussed in the technical literature addressing hydraulic fracturing. The discussion of transport through fractures, below, is based on authors' observations, opinions and conclusions related to natural fractures.

There appear to be events suggesting that a hydraulic connection may exist between the FF and shallow aquifers.

In the literature that EPA reviewed, few authors had considered conduits other than pre-existing wells, un-cemented well annuli, etc., as pathways for methane migration from the CBM unit. However, Chafin (1994) addressed natural fractures and concluded that they are not substantial migration pathways:

> "Chemical and geological evidence suggests that substantial quantities of natural gas are not migrating from deep gas-bearing formations along natural fractures (joints and faults) into the shallow subsurface environment beneath the study area. Comparisons between soil-gas-methane concentrations measured adjacent to 352 gas-well casings and 192 ground-water sites (used as background measurements) indicate that gas-well annuli are more important than fractures for upward migration of gas. If natural fractures were the important conduits for upward migration, greater soil-gas-methane concentrations probably would be measured at some of the ground water sites located on or near major fracture zones. The relatively systematic vertical and north-south variation in produced-gas maturities for formations beneath the study area argues against substantial vertical migration of gas and for effective trapping near source rocks. Most delta $C^{13}{}_1$ values for near-surface environmental samples indicate reasonably distinct signatures of production gas from individual gas-yielding formations beneath the study area; fractures penetrating two or more producing formations would be expected to generally transport gas with mixed signatures to the near-surface environment." (pgs. 43-44)

Chafin (1994, pg. 1) stated that because gas diffusion through natural fractures is an extremely slow process, one whose results would only be perceptible in geologic timeframes, "... manmade conduits probably account for most of the upward migration of gas to the near-surface environment of the study area."

Beckstrom and Boyer (1991) reported on Amoco tracer surveys of hydrofractures in the SJB, and believe that the massive shales above and below the FF keep hydraulic fractures within the Fruitland:

> "Massive shales above and below the Fruitland formation control frac height growth and prevent fracture stimulations from intercepting groundwater in the study area. Frac height limitation by the bounding shales has been confirmed by post frac tracer surveys....
>
> The ten interpretable surveys confirm that the fracs were found to be contained below the Kirtland shale in all cases." (pg. 377)

A study controlling for preexisting wells (that is, there are no preexisting wells), was performed in Bayfield, Colorado. This study found little adverse impact from CBM production. The BLM (1999) reported that:

> "The propensity for contamination of groundwater by methane gas was recognized as a valid concern. In 1991 this issue was addressed in the preparation of a joint BLM/USFS …. Environmental Impact Statement (EIS) for the proposed 64-well coalbed methane (CBM) drilling project in the HD Mountains east of Bayfield, Colorado. In this newly developed area, all wells were to be CBM wells. The potential problem of adversely affecting older conventional well bores, often characterized by incomplete isolation of the Fruitland Formation, was

> irrelevant due to the lack of conventional wells in this area.... Sixty-five to seventy water wells, largely on the periphery of the sparsely inhabited interior of the HD EIS study area, have been monitored in 1993 and 1996 in an effort to provide early warning of any discernable gas production-induced groundwater contamination. So far virtually no adverse water quality impacts have been documented, although concerns have arisen off the northwestern flank of the study area where high levels of thermogenic methane with isotopic signatures similar to Mesaverde gas have been documented in monitoring on private lands." (section on BLM Environmental Monitoring - HD Mountains)

The BLM (1999) reported that it jointly performed a study with the Colorado Gas and Oil Conservation Commission (COGCC) to determine the effectiveness of gas-well remediation, in an effort to determine whether or not leaking gas wells were the conduits that transmitted gas from the FF to the shallow aquifers:

> "One hundred and twenty water wells were re-tested during the 1998 joint BLM/COGCC effort. Water wells located in the vicinity of remediated gas wells were chosen for this study to evaluate groundwater quality changes in domestic water wells by comparison with prior baseline values.... Preliminary findings of this 1998 study are encouraging. Based upon prior studies of methane concentration in groundwater (Pine River Investigative Team Report, 1995), the criteria denoting significant entrained methane concentration change was established at a 10-fold increase for entrained methane concentrations of less than 0.1 mg/L. An increase/decrease of 5.0 mg/L is considered significant when concentrations vary between 1.0 mg/L and 30 mg/L. (Due to potential losses of methane during collection of methane-saturated water, concentrations in excess of 30 mg/L methane in water are inconclusive for comparison of precise values.) Using the stipulated criteria, a preview of this 1998 study indicates that 32 water wells tested in 1998 in proximity to remediated gas wells exhibited a reduction in entrained methane concentration.... Eleven wells showed an increase. Six wells tested in 1998 had no prior established baseline for comparison. Sixty-seven wells showed no definitive change. Of these latter 67 wells showing no statistically significant change, latest test values were lower at 44 sites, higher at 14 wells, and essentially identical to earlier tests at 15 locations." (Remediation Results Across the San Juan Basin of Colorado to Date)

It appears, from this study, that although remediating gas wells has some positive impact on the reduction of methane in shallow water wells, the relation between remediation and lowered methane levels is complex. The absence of a clear "one to one" relationship between the two may result from a lingering presence of methane in the shallow aquifer, after remediation of the gas wells has been accomplished.

In a case of likely transport, in part, by cathodic protection groundbeds, Beckstrom and Boyer (1991, pg. 375) report:

> "About thirty miles east of Cedar Hill, a direct correlation was found between charged annuli and flowing groundbeds, which confirmed the shallow aquifer gas crossflow theory. In those cases, groundbed gas and water flow was terminated when the Fruitland coal was cemented in the offsetting wells."

Other problems associated with CBM production include explosive levels of methane and toxic levels of hydrogen sulfide accumulating under buildings and in living spaces and spontaneous combustion and continued burning of completely dewatered coalbeds. By-products, such as polyaromatic hydrocarbons, from the underground fires could potentially lead to contamination of USDWs. There is a high level of awareness of the problems associated with CBM production in the area, and authorities from local, county, state and federal agencies and the Southern Ute Tribe environmental quality office are involved in addressing them.

Based on what EPA has read and on oral communications, it appears that in deep CBM settings hydrogeologically similar to the San Juan Basin, the likely high-conductivity conduits transporting methane, and/or possibly HF fluids, from CBM units to upper, shallow aquifers are existing wells in need of remediation, and similar manmade features, rather than natural or manmade fractures, which likely transport little, if any, fluid/gas. However, near the CBM outcrop along part of the Basin rim, it is possible that natural fractures may serve as migration pathways.

6.2 Powder River Basin (Wyoming and Montana)

EPA spoke with several individuals familiar with CBM activity in the Powder River Basin (PRB) area who believe CBM production is causing water quantity issues. These individuals have reported that dewatering during CBM production has resulted in loss of water from wells and flooding problems on the surface. In the PRB, many of the drinking water wells are screened and completed in the same formation being dewatered for methane production. EPA followed up, and according to a consulting hydrogeologist, as much as 1,000,000 gallons of water are pumped from each coalbed methane production well during its lifetime, and consequently, the aquifer has dropped 200 feet in some areas (Merchat, 1999). EPA has also learned that as of 1999, oil and gas companies have drilled 2,000 wells in the Powder River Basin, and they reportedly plan to drill 15,000 in total (Merchat, 1999). However, EPA also has information that there are other aquifers available in deeper zones, and the oil and gas companies have drilled new water wells in those aquifers for individual citizens. Summaries of reported incidents are documented here. However, hydraulic fracturing is not frequently used in the Powder River Basin, and no citizens from that area have reported problems relating to hydraulic fracturing.

6.2.1 Summary of Reported Incidents

- EPA contacted both the state and local offices of the Wyoming Health Department and the Water Quality Division of the Wyoming Department of Environmental Quality to determine if these departments had received complaints of water quality degradation from coalbed methane production. Local authorities reported that one citizen complained of black sediments in his water but most of the concern is centered around water loss and flooding, which results from large quantities of water being discharged at the surface (Heath, 1999). There has been discussion among stakeholders regarding the handling of large volumes of water brought to the surface during coalbed methane production. Some citizens remain concerned about the consequences of dewatering aquifers, which include loss of the resource, effects on soil chemistry, flooding, and the potential for coalbed fires and subsidence.

- EPA spoke with a consultant for the Powder River Basin Resource Council (PRBRC), a citizens group formed around environmental issues associated with coalbed methane production (Merchat, 1999). He stated that the biggest concern among people in the area is loss of water, however, some have had problems with increased methane content in their water. He said people reported methane in the water results in frothing and bubbles. The water is generally used for agricultural purposes and for drinking water. He said that each methane well produces millions of gallons of water in its lifetime. The discharge of water has created new ponds and swamps that are not naturally occurring in that region. The secondary effects from pumping water is subsidence and clinker beds (burning coal). When underground coal catches fire from lightning, it burns until it reaches ground water; however, if there is no ground water, the fire will continue to burn. The cost of manually extinguishing those fires is enormous. Furthermore, the burning of the coal can leave behind benzo(a)pyrene and other polycyclic aromatic hydrocarbons that are toxic and/or carcinogenic and could affect drinking water.

EPA Region 8 is participating in a study that addresses the environmental impacts from all aspects of CBM development and not just hydraulic fracturing.

6.3 Black Warrior Basin (Alabama)

The *LEAF (Legal Environmental Assistance Foundation) v. EPA* case was initiated due to an alleged incident of water quality impact related to coalbed methane activities in Alabama. As previously discussed in Chapter 1, the Court decided the State of Alabama must regulate hydraulic fracturing of coalbed methane wells in order to maintain authority over their UIC program. Alabama adopted hydraulic fracturing regulations in 1999 and continues to have authority over their UIC program. Summaries of reported incidents are presented in section 6.3.1 below.

6.3.1 Summary of Reported Incidents

- In the drinking water well case that precipitated *LEAF v EPA*, a citizen complained that drinking water from his well had a milky white substance in it and had strong odors shortly after a fracturing event. He also reported that six months after the fracturing event his water had increasingly bad odors and occasionally contained black coal fines. The EPA Administrative Record regarding the Alabama Class II UIC Program contains other similar descriptions of well water problems.

- Another Alabama citizen contacted EPA reporting problems with her drinking water well that began in 1989. The citizen reported that her property was located near a coalbed methane gas well and that there was coal mining in the area. According to her letter, she believes hydraulic fracturing of the coalbed methane well impacted her drinking water well, and that coal resource exploitation in the area caused various, significant environmental damage. The individual believed that the hydraulic fracturing contributed to well contamination because shortly after a fracturing event, her kitchen water contained globs of black, jelly-like grease and smelled of petroleum. She said her drinking water turned brown and contained slimy, floating particles. She reported that her neighbors also said their water smelled like petroleum.

  She included as an attachment a letter from the Alabama State Oil and Gas Board approving the use of proppants tagged with radioactive material. Their approval was based on the hydrogeology and the absence of water wells in the immediate area, depths of coal intervals to be fractured, well construction, and adherence to a program designed to monitor and contain radioactive material at the surface. Also attached was a letter from EPA Region IV describing analytical results for samples EPA collected from her drinking water well on June 26, 1990. The results indicated no purgeable and extractable organic compounds were detected. Additionally, the letter said that a water/oil inter-phase detector was used to determine if petroleum products were floating in the well and none were detected.

- An Alabama homeowner complained to the Natural Resources Defense Council that recovered hydraulic fracturing fluid from a nearby coalbed methane well installation was allowed to drain from the coalbed methane well site to a location near her home. She claims that this fluid was initially obtained from an abandoned strip-mining quarry that had been used as a landfill for municipal and industrial waste. As this fluid drained from the fracturing site, the homeowner asserts that it killed all animal and plant life in its path. She further stated that shortly after this fracturing event and the associated runoff, her 110-foot deep drinking water well became contaminated with brown, slimy, petroleum-smelling fluid that was similar to the discharged fracturing fluid from the coalbed methane well site.

- A citizen's response in Water Docket W-01-09 indicated that her drinking water well had become filled with methane gas, causing it to hiss. The tap water became cloudy, oily, and had a strong, unpleasant odor. In addition, the tap water left behind an oily film and contained fine particles. The drinking water well owner had her well tested by a private consultant, who confirmed the presence of methane in the drinking water well.

> The Alabama Oil and Gas Board tested this drinking water well but only looked for naturally occurring contaminants. The EPA sampled and tested this drinking water well also, but did not do so until six months after the event. No mention is made of the analytical results obtained from the drinking water well by these agencies.

6.3.2 State Agency Follow-Up (Alabama Oil and Gas Board)

Because the *LEAF v. EPA* case originated in Alabama, the water well that was reportedly contaminated has been sampled and significant resources from the Alabama Department of Environmental Management, the Alabama Oil and Gas Board (OGB), and EPA Region 4 have been devoted to determining whether or not hydraulic fracturing impacted the well. The Alabama OGB reported to EPA that they investigate every complaint that comes into their office and they do not believe that hydraulic fracturing has impacted water wells.

As a result of the Court's decision, however, the Alabama OGB adopted hydraulic fracturing regulations in 1999. Per Alabama's hydraulic fracturing regulations, fracturing fluids cannot exceed applicable primary drinking water regulations under 40 C.F.R. 141 (MCLs), or otherwise adversely affect the health of persons. Fracturing is prohibited from ground surface to 299 feet below ground surface (bgs). For all fracture jobs performed between 300 feet and 749 feet bgs, the company must perform a reconnaissance of fresh-water supply wells within 1/4 mile of the well to be fractured, submit a fracturing program to the OGB, and perform a cement bond log analysis. For fracturing events performed between 750 feet and 1,000 feet bgs, only a cement bond log is required. For fracturing events performed below 1,000 feet bgs, operators must submit to the OGB the depth to be fractured, well construction information, cementing specifications, and logs identifying overlying, impervious strata.

6.4 Central Appalachian Basin (Virginia and West Virginia)

EPA became aware of several complaints relating to the effects of coalbed methane production on sources of drinking water in the southwestern portion of Virginia through correspondence initiated by citizens. Information about water quality incidents were acquired through meetings and telephone conversations with members of the Virginia Division of Oil and Gas within the Department of Mines, Minerals and Energy (DMME), local health officials, and representatives of a county citizens group. In total, the Virginia DMME provided EPA with over 70 "Complaint Detail Reports" (registered between 1990 and 2001) that were related to impacts to sources of drinking water by coalbed methane development.

Although the majority of the incidents outlined in the complaints pertain to water-loss issues, approximately one-quarter of these are related to water quality. Specifically, Virginia residents living near coalbed methane production areas reported private well and spring water contamination evidenced by oily films, soaps, iron oxide precipitates, black sediments, methane gas, and bad odor and taste. Primarily, however, complaints deal with the loss of water in wells. Reports range from supply rates being noticeably reduced, to total loss of drinking water from domestic drinking water wells. Summaries of reported incidents and state follow-up are discussed in sections 6.4.1 and 6.4.2 below.

6.4.1 Summary of Virginia Incidents

- Complaints reported soap bubbles flowing from residential household fixtures. The DMME attributes soaps coming out of water faucets and to the drilling process associated with coalbed methane well installation. Soaps are used to extract drilling cuttings from the borehole because the foam expands, rises, and as it rises, it carries the cuttings to the surface quite efficiently (Wilson, 2001). These soaps may migrate from the borehole into the drinking water zone that supplies private wells during drilling of the shallow portion of the hole and before the required groundwater casing is cemented in place. In the few occurrences of soap contamination, water was provided until the soaps were completely purged from the contributing area surrounding their water well.

- In early August of 2001, EPA met with approximately 15 to 20 citizens from Buchanan and Dickenson Counties, Virginia. Coalbed methane production activity is steadily increasing in the area surrounding Buchanan County since the coal reserves in this area have proven to be extremely profitable sources for coalbed methane extraction for the coal mining and gas industry in recent years (Wilson, 2001). The subjects of the citizen complaints were very similar to those logged in the DMME complaint reports. Attendees described the presence of black sediments, iron precipitates, soaps, diesel fuel smells and increased methane gas in drinking water from their wells. One resident brought in a water sample collected from her drinking water well. The water was translucent with a dark grey color and with dark black suspended sediment. Several other citizens reported drinking water supplies diminishing or drying up entirely. One resident of Buchanan County stated that he had an ample water supply from his drinking their well for over 54 years, until shortly after coalbed methane wells were installed on his property. He reported that within 60 days of the coalbed methane well installations, his 276-foot deep drinking water supply well, that used to produce over 20 gallons per minute of potable flow, dried up. Another resident mentioned that over 380 homes in the region do not have potable water as a result of coalbed methane mining activities in the region.

  Most of the residents explained that their complaints to the state usually resulted in investigations without resolution. Some residents mentioned that the gas companies were providing them with potable water to compensate for the contamination or loss of their drinking water wells. However, the residents expressed that this was not adequate compensation for the impacts to, or loss of, their private drinking water supply.

- EPA was able to record numerous complaints through telephone conversations and electronic messaging with Virginia residents who reported that they believed their drinking water wells had been impacted by coalbed methane industry activities. All the logged complaints were from Buchanan and Dickenson counties. Complaints include water loss, soapy water, diesel odors, iron and sulfur in wells, rashes from showering, gassy taste and murky water. One report discusses a miner who was burned by a fluid, possibly hydrochloric acid used in hydraulic fracturing, that infiltrated into a mineshaft. Another report describes the contamination of a stream and the resulting fish kills created by the runoff from drilling fluids. One complainant explained that several thousand wells have "…gone dry, overnight." According to individuals EPA spoke with, compensation to homeowners for these impacts is in the form of money, newly drilled wells to replace dry or contaminated wells or temporary provision of potable water, which is supplied "…until things clear out."

6.4.2 State Agency Follow-Up (Virginia DMME)

The Virginia DMME, Division of Gas and Oil (DGO), is responsible for responding to environmental issues associated with oil and gas development, and investigates every water problem reported. Their response may include an interview with the citizen reporting the problem, a site visit, water well testing, and/or a review of the physical aspects of the water well and surrounding activities. According to Bob Wilson of the DMME, they test for contaminants that may be introduced by drilling such as chlorides, oil and grease, and volatile organics. The results of those analyses are compared to baseline values. The DMME witnesses surface casing and plugging jobs as part of their oversight duties. They review information from drilling and completion reports to assist with investigations into complaints.

Based on investigations of the more than 70 complaints received, the DMME believes that coalbed methane production has not affect private drinking water wells. They have recognized soap migrating into drinking water wells, but they consider this only a transient problem. While a number of complaints report a noticeable reduction or a total loss of drinking water supply, in almost all cases, the state investigator determined that their water loss was not likely due to local hydraulic fracturing events or coalbed methane production activity. The main reasons for complaint dismissal by the DMME appear to be the following:

- The distance from the private well to the nearest coalbed methane well is too far (1,500 feet or greater) to have any impact.
- There is no hydrologic connection between the water contribution zones of the private and coalbed methane wells, therefore it is physically impossible for coalbed methane wells to impact private drinking water wells.
- The well construction was executed according to DMME regulatory guidelines, therefore a sufficient buffer exists between the private well and the coalbed methane well.
- The existing supply was reduced because of the recent drought conditions experienced in the region.

- The complainant experienced mechanical difficulty with their pumping system, which has led to a reduction in pumped water. Supply has not been impacted.

According to the director of the Virginia DMME, the impacts of many years of mining may have affected drinking water wells, but coalbed methane has not.

6.5 Conclusion

This chapter has not attempted to establish a definitive cause and effect relationship between hydraulic fracturing and the contamination of drinking water wells and supplies. The technical evidence required to establish a definitive relationship between a specific hydraulic fracturing event and a specific contaminated well would require the collection of significant data, possibly site-specific water quality and hydrogeologic data, that is beyond the scope of this study.

Instead, we present information (in addition to technical, conceptual, or theoretical information presented previously) on personal experiences with regard to coalbed methane activities and their potential (or perceived potential) to impact drinking water wells. These personal accounts regarding potential incidences in four producing coal basins across the U.S. do not present scientific findings. However, the body of reported problems considered collectively suggest that water quality (and quantity) problems might be associated with some of the variety of production activities common to coalbed methane extraction. These production activities include surface discharge of fracturing and production fluids, aquifer/formation dewatering, water withdrawal from production wells, methane migration through conduits created by drilling and fracturing practices, or any combination of these. Other potential sources of drinking water problems include various aspects of resource development, naturally-occurring conditions, population growth and historical practices.

Table 6.1 on the following page provides a summary of the incidents described previously in this chapter that together present an informal record of a potential or perceived association of drinking water quality (and quantity) problems with coalbed methane development and extraction activities. In several of the coalbed methane investigation areas, local agencies concluded that hydraulic fracturing could not affect drinking water wells. Either horizontal distance between the coalbed methane production wells and the drinking water wells was too great, or the production wells and drinking water wells were drilled to and are active within subsurface horizons separated by significant vertical distances. In at least two basins (the Central Appalachian Basin and the Powder River Basin), it was reported that coal and gas companies either provided alternate sources of drinking water or drilled new drinking water wells for homeowners who had drinking water wells allegedly contaminated by coalbed methane operations.

Table 6-1. Summary of Alleged Water Quality/Quantity Incidents

	Water Contamination Associated with Methane	Water Contamination Associated with Fracturing Fluids	Water Contamination Reported *Without* Specific Mention of CBM Activity	Water Depletion or Loss Associated with CBM Activity	Non-Water Related Impacts Associated with CBM Activity
San Juan Basin (New Mexico, Colorado)	• Increased methane and hydrogen sulfide in water wells, pumphouses, and homes. • Claims of data showing methane concentrations in wells increased by 1000 ppm. • Improperly abandoned wells lead to methane migration from deep coal seams to shallow soils.	Information not available	• Appearance of anaerobic bacteria in wells and transient appearance of particulates. • Black particulate in water. • Cloudy water with grayish sediment found 2 days after fracturing.	• Complaints of loss of water due to CBM development.	• Spots of dead vegetation coincident with CBM production.
Powder River (Wyoming, Montana)	• Methane causes drinking water to froth and bubble.	Information not available	Information not available	• Loss of water in wells from CBM development. • Aquifer dropped up to 200 feet in some areas.	• Discharged water creates artificial ponds and swamps not indigenous to region. • Coal ignites from lightning and creates underground fires that burn because of dewatered aquifer. Toxic by-products could contaminate water.

Table 6-1. (Continued)

	Water Contamination Associated with Methane	Water Contamination Associated with Fracturing Fluids	Water Contamination Reported *Without* Specific Mention of CBM Activity	Water Depletion or Loss Associated with CBM Activity	Non-Water Related Impacts Associated with CBM Activity
Black Warrior (Alabama)	• Drinking water well was hissing due to a high concentration of methane gas. Water also had a strong, unpleasant odor.	• Citizen believes drinking water well became contaminated with a brown, slimy, petroleum-smelling fluid after recovered fracturing fluid drained from a CBM well site to an area near this homeowner's house.	• Well water with milky white substance and strong odor. • Well water with black fines, globs of black jellied grease and smelled of petroleum. • Well water turned brown and had long, slimy tags of floating gunk.	Information not available	• Hydraulic fracturing fluid reportedly discharged. Animal/plant life impacted.
Central Appalachian (Virginia, West Virginia)	• Well water contaminated by methane gas had bad taste and odor.	• Citizens believes fish kills associated with fracturing fluid discharged into streams. • VA DMME states that soap bubbles in residential water fixtures are linked with CBM activities	• Private well contamination by oily films, soaps, iron oxides precipitates, black sediments, bad odor and taste, diesel fuel smells, and murky water. • Soap bubbles flowing from residential household fixtures. • Resident provided EPA with well water sample that was translucent with dark black sediments.	• Average of 10-12 complaints per year to Virginia Dept of Mines, Minerals, and Energy involve reports of water supplies diminishing or disappearing entirely. • Over 380 homes in Buchanan County without potable water as a result of CBM development.	• Residents develop rashes from showering. • Miner burned from acid that seeped into mine shaft.